CLAIMS

WHAT IS CLAIMED IS:

1. An integrated optical apparatus comprising:

a planar waveguide having an elongated guiding portion and a grating coupler;

said grating coupler comprising a plurality of gratings having respective scatter-cross-sections adapted to scatter light along at least a portion of a predetermined optical path and a Distributed Bragg Reflector (DBR) positioned with respect to said grating such that light scattered outside said portion of said optical path is reflected by the DBR towards said gratings.

2. The integrated optical apparatus of Claim 1, wherein said DBR comprises a multilayer stack comprising multiple layers of material.

3. The integrated optical apparatus of Claim 2, wherein said DBR comprises alternating layers of semiconductor and dielectric material.

4. The integrated optical apparatus of Claim 2, wherein said DBR comprises alternating layers of dielectric material.

5. The integrated optical apparatus of Claim 2, wherein said grating coupler is disposed with respect to an optical element to couple light of a predetermined wavelength between said optical element and said elongated guiding portion of said planar waveguide, said optical element being oriented at an angle with respect to said optical element and said multiple layers of said DBR having thicknesses to provide coherent reflection of said light having said wavelength and directed at said angle of incidence of the light.

6. The integrated optical apparatus of Claim 1, wherein said DBR comprises silicon.

7. The integrated optical apparatus of Claim 6, wherein said DBR comprises dielectric selected from the group consisting of oxide and nitride.

8. The integrated optical apparatus of Claim 1, wherein said planar waveguide and said DBR are formed on a substrate and said DBR is disposed between said planar waveguide and said substrate such that light scattered outside said portion of said optical path and toward said substrate is reflected by the DBR towards said gratings.

9. The integrated optical apparatus of Claim 8, wherein DBR is formed on a layer of material formed on said substrate.

10. A method of fabricating a waveguide grating coupler for coupling light having a predetermined wavelength between an optical element and a waveguide, said optical element and said waveguide juxtaposed such that said light propagates along an optical path therebetween at an angle with respect to said optical coupler, said method comprising:

providing a Distributed Bragg Reflector (DBR) on a substrate by forming alternating layers of material having relatively high and low refractive indices and thicknesses that provide enhanced reflectivity for said predetermined wavelength and said angle of said optical path;

forming a planar waveguide over said DBR by forming a slab and cladding above said DBR; and

forming an optical grating by patterning a plurality of diffractive features in said waveguide.

11. The method of Claim 10, wherein forming said DBR comprises growing alternating layers of relatively high and low index material on said substrate.

12. The method of Claim 11, wherein forming said DBR comprises growing alternating layers of relatively silicon and dielectric on said substrate.

13. The method of Claim 10, further comprising forming patterned features said slab to provide lateral confinement of light in said waveguide.

14. An integrated optical apparatus comprising:

a planar waveguide having an elongated guiding portion and a grating coupler;

said grating coupler comprising a plurality of gratings having respective scatter-cross-sections adapted to scatter light along at least a portion of a predetermined optical path; and

a pair of Distributed Bragg Reflectors (DBRs) positioned on opposite sides of said gratings such that light scattered outside said portion of said optical path is reflected by DBRs towards said gratings.

15. The integrated optical apparatus of Claim 14, wherein said pair DBRs are spaced apart from each other a distance to provide a optical cavity resonance for said scattered light.

16. The integrated optical apparatus of Claim 14, wherein said planar waveguide and said pair of DBRs are formed on a substrate, one of said DBRs being disposed between said planar waveguide and said substrate such that light scattered outside said portion of said optical path and toward said substrate is reflected by DBRs towards said gratings.

17. The optical system of Claim 14, wherein said grating coupler comprises a waveguide selected from the group consisting of a channel waveguide, a ridge waveguide, a strip loaded waveguide, and a strip loaded waveguide having a low index transition region.

18. An integrated optical apparatus comprising:

a planar waveguide on a substrate;

said waveguide having an elongated guiding portion and a grating coupler;

said grating coupler comprising a plurality of gratings having respective scatter-cross-sections adapted to scatter light along at least a portion of a predetermined optical path and a gas-filled cavity, at least a portion of which is in the substrate;

said cavity positioned with respect to said gratings such that light scattered outside said portion of said optical path is reflected by said cavity towards said gratings.

19. The optical system of Claim 18, wherein said grating coupler includes sidewalls to confine light in a transverse direction.

20. The optical system of Claim 19, wherein said grating coupler comprises a waveguide selected from the group consisting of a channel waveguide, a ridge waveguide, a strip loaded waveguide, and a strip loaded waveguide having a low index transition region.

21. The integrated optical apparatus of Claim 18, wherein said substrate comprises a silicon wafer.

22. The integrated optical apparatus of Claim 21, wherein said substrate further comprises a silicon dioxide layer formed on said silicon wafer.

23. The integrated optical apparatus of Claim 22, wherein said substrate further comprises one or more layers of material formed on said silicon wafer.

24. The integrated optical apparatus of Claim 18, wherein said gas-filled cavity is filled with air.

25. The integrated optical apparatus of Claim 18, wherein said waveguide comprises cladding and gas-filled cavity is in at least a portion of said cladding.

26. A method of fabricating a waveguide grating coupler comprising:

forming a planar waveguide on a substrate;

etching an area adjacent the waveguide down to a level beneath said waveguide;

laterally etching beneath said waveguide to form a cavity under said waveguide; and

forming an optical grating by patterning a plurality of diffractive features in said waveguide.

27. The method of Claim 26, wherein said etching comprises selectively etching material beneath said waveguide with an etchant that preferable etches said material without substantially etching said waveguide.

28. An integrated optical apparatus comprising:

a planar waveguide having an elongated guiding portion and a grating coupler;

said grating coupler comprising:

(a) a plurality of gratings having respective scatter-cross-sections adapted to scatter light along at least a portion of a predetermined optical path;

(b) a cladding on said plurality of gratings; and

(c) an anti-reflection coating on said cladding for reducing reflections.

29. The integrated optical apparatus of Claim 28, wherein said anti-reflection coating comprises a multilayer stack.

30. The integrated optical apparatus of Claim 29, wherein said anti-reflection coating comprises a quarter-wave stack.

31. The integrated optical apparatus of Claim 29, wherein said multilayer stack comprises multiple layers of relatively high and low index material having thicknesses selected to provide reduced reflection for light of a predetermined wavelength incident on said anti-reflection coating at a predetermined angle.

32. The integrated optical apparatus of Claim 31, further comprising an optical element oriented with respect to said grating coupler so as to provide an optical path directed at said predetermined angle with respect to said grating coupler, said grating coupler coupling light between said planar waveguide and said optical element.

33. The integrated optical apparatus of Claim 28, wherein said anti-reflection coating comprises alternating layers of semiconductor and dielectric material.

34. The integrated optical apparatus of Claim 28, wherein said anti-reflection coating comprises alternating layers of silicon and dielectric material.

35. The integrated optical apparatus of Claim 34, wherein said dielectric material is selected from the group consisting of oxide and nitride.

36. The integrated optical apparatus of Claim 28, wherein said anti-reflection coating comprises multiple layers of dielectric material.

37. An integrated optical apparatus, comprising:

a planar waveguide having an elongate guiding portion and a grating coupler, said coupler having at least a flared waveguide portion comprising a relatively narrow end portion and a relatively wide end portion, said flared portion having a grating positioned to couple light between said coupler and an optical element,

wherein said grating comprises curved elongate scattering elements having curvatures defined by substantially elliptical paths so as to couple plane waves between said waveguide grating coupler and said optical element.

38. The integrated optical apparatus of Claim 37, wherein (i) said elongate scattering elements have respective scatter cross-sections adapted to scatter light along at least a portion of a predetermined optical path and (ii) a pair of Distributed Bragg Reflectors (DBRs) are positioned on opposite sides of said grating such that light scattered outside said portion of said optical path is reflected by said DBRs towards said grating.

39. The integrated optical apparatus of Claim 38, wherein said pair of DBRs are spaced apart from each other a distance to provide an optical cavity resonance for said scattered light.

40. The integrated optical apparatus of Claim 38, wherein said planar waveguide and said pair of DBRs are formed over a substrate, one of said DBRs being disposed between said planar waveguide and said substrate such that light scattered outside said portion of said optical path and toward said substrate is reflected by said one of said DBRs toward said grating.

41. The integrated optical apparatus of Claim 37, wherein (i) said elongate scattering elements have respective scatter cross-sections adapted to scatter light along at least a portion of a predetermined optical path and (ii) a gas-filled cavity is positioned with respect to said

grating such that light scattered outside said portion of said optical path is reflected by said cavity towards said grating.

42. The integrated optical apparatus of Claim 41, further comprising a substrate, said planar waveguide being disposed over said substrate and at least a portion of said gas-filled cavity being in said substrate.

43. The integrated optical apparatus of Claim 41, wherein said gas-filled cavity is filled with air.

44. The integrated optical apparatus of Claim 41, wherein said planar waveguide comprises cladding and said gas-filled cavity is in at least a portion of said cladding.

45. The integrated optical apparatus of Claim 37, further comprising:

a cladding over said grating; and

an anti-reflection coating over said cladding for reducing reflections.

46. The integrated optical apparatus of Claim 45, wherein said anti-reflection coating comprises a multilayer stack.

47. The integrated optical apparatus of Claim 45, wherein said anti-reflection coating comprises alternating layers of semiconductor and dielectric material.

48. The integrated optical apparatus of Claim 45, wherein said anti-reflection coating comprises alternating layers of silicon and dielectric material.

49. The integrated optical apparatus of Claim 45, wherein said anti-reflection coating comprises multiple layers of dielectric material.

50. The integrated optical apparatus of Claim 45, wherein said dielectric material is selected from the group consisting of silicon dioxide and silicon nitride.

51. A waveguide grating coupler for coupling light between a waveguide and an optical element having a substantially Gaussian mode profile, said waveguide grating coupler comprising:

a planar guiding portion optically connected to said waveguide, said planar guiding portion having first and second ends and an optical power distribution therein that decreases between said first and second ends; and

a plurality of elongate scattering elements having respective scatter cross-sections arranged along at least a portion of said planar guiding portion to couple light having a substantially Gaussian intensity distribution between said planar guiding portion and said optical element, said elongate scattering elements having at least one characteristic which varies in magnitude among at least a group of said elongate scattering elements, said magnitude of said characteristic controlling at least in part said scatter cross-sections of said elongate scattering elements,

wherein said magnitude of said characteristic of said group of elongate scattering elements varies irregularly, said magnitude for said group of elongate scattering elements changing with position along said planar guiding portion at a rate that is discontinuous.

52. The waveguide grating coupler of Claim 51, wherein (i) said plurality of elongate scattering elements have respective scatter cross-sections adapted to scatter light along at least a portion of a predetermined optical path and (ii) said planar guiding portion further comprises a Distributed Bragg Reflector (DBR) positioned with respect to said elongate scattering elements such that light scattered outside said portion of said optical path is reflected by said DBR towards said elongate scattering elements.

53. The waveguide grating coupler of Claim 52, wherein said DBR comprises a multilayer stack comprising multiple layers of material.

54. The waveguide grating coupler of Claim 53, wherein said DBR comprises alternating layers of semiconductor and dielectric material.

55. The waveguide grating coupler of Claim 53, wherein said DBR comprises alternating layers of dielectric material.

56. The waveguide grating coupler of Claim 53, wherein said grating coupler is disposed with respect to said optical element to couple light of a predetermined wavelength between said optical element and said planar guiding portion, said optical element being oriented at an angle with respect to said planar guiding portion and said multiple layers of said DBR having thicknesses to provide coherent reflection of said light having said wavelength and directed at said angle of incidence of the light.

57. The waveguide grating coupler of Claim 52, wherein said DBR comprises silicon.

58. The waveguide grating coupler of Claim 57, wherein said DBR comprises dielectric selected from the group consisting of silicon dioxide and silicon nitride.

59. The waveguide grating coupler of Claim 52, wherein said planar guiding portion and said DBR are formed over a substrate and said DBR is disposed between said planar guiding portion and said substrate such that light scattered outside said portion of said optical path and toward said substrate is reflected by said DBR toward said elongate scattering elements.

60. The waveguide grating coupler of Claim 59, wherein said DBR is formed on a layer of material formed over said substrate.

61. The waveguide grating coupler of Claim 51, wherein (i) said plurality of elongate scattering elements have respective scatter cross-sections adapted to scatter light along at least a portion of a predetermined optical path and (ii) said planar guiding portion further comprises a pair of Distributed Bragg Reflectors (DBRs) positioned on opposite sides of said elongate scattering elements such that light scattered outside said portion of said optical path is reflected by said DBRs toward said elongate scattering elements.

62. The waveguide grating coupler of Claim 61, wherein said pair of DBRs are spaced apart from each other a distance to provide an optical cavity resonance for said scattered light.

63. The waveguide grating coupler of Claim 61, wherein said planar guiding portion and said pair of DBRs are formed over a substrate, one of said DBRs being disposed between said planar guiding portion and said substrate such that light scattered outside said portion of said optical path and toward said substrate is reflected by said one of said DBRs towards said elongate scattering elements.

64. The waveguide grating coupler of Claim 51, further comprising a gas-filled cavity, at least a portion of which is in the substrate, said plurality of elongate scattering elements having respective scatter cross-sections adapted to scatter light along at least a portion of a predetermined optical path, wherein said cavity is positioned with respect to said elongate scattering elements such that light scattered outside said portion of said optical path is reflected by said cavity towards said elongate scattering elements.

65. The waveguide grating coupler of Claim 64, wherein said gas-filled cavity is filled with air.

66. The waveguide grating coupler of Claim 64, wherein said planar guiding portion comprises cladding and gas-filled cavity is in at least a portion of said cladding.

67. The waveguide grating coupler of Claim 51, further comprising

a cladding over said plurality of elongate scattering elements; and

an anti-reflection coating over said cladding for reducing reflections.

68. The waveguide grating coupler of Claim 67, wherein said anti-reflection coating comprises a multilayer stack.

69. The waveguide grating coupler of Claim 67, wherein said anti-reflection coating comprises alternating layers of semiconductor and dielectric material.

70. The waveguide grating coupler of Claim 67, wherein said anti-reflection coating comprises alternating layers of silicon and dielectric material.

71. The waveguide grating coupler of Claim 67, wherein said anti-reflection coating comprises multiple layers of dielectric material.

72. The waveguide grating coupler of Claim 67, wherein said dielectric material is selected from the group consisting of silicon dioxide and silicon nitride.

73. An integrated optical apparatus, comprising:

a planar waveguide having an elongate guiding portion and a grating coupler, said grating coupler comprising a grating comprising a plurality of elongate scattering elements including a first elongate scattering element that is segmented into scattering portions and a second elongate scattering element that is unsegmented.

74. The integrated optical apparatus of Claim 73, wherein (i) said plurality of elongate scattering elements have respective scatter cross-sections adapted to scatter light along at least a portion of a predetermined optical path and (ii) a Distributed Bragg Reflector (DBR) is positioned with respect to said grating such that light scattered outside said portion of said optical path is reflected by said DBR toward said grating.

75. The integrated optical apparatus of Claim 74, wherein said DBR comprises a multilayer stack comprising multiple layers of material.

76. The integrated optical apparatus of Claim 75, wherein said DBR comprises alternating layers of semiconductor and dielectric material.

77. The integrated optical apparatus of Claim 75, wherein said DBR comprises alternating layers of dielectric material.

78. The integrated optical apparatus of Claim 75, wherein said grating coupler is disposed with respect to an optical element to couple light of a predetermined wavelength between said optical element and said elongated guiding portion of said planar waveguide, said optical element being oriented at an angle with respect to said optical element and said multiple layers of said DBR having thicknesses to provide coherent reflection of said light having said wavelength and directed at said angle of incidence of the light.

79. The integrated optical apparatus of Claim 74, wherein said DBR comprises silicon.

80. The integrated optical apparatus of Claim 74, wherein said DBR comprises dielectric selected from the group consisting of silicon dioxide and silicon nitride.

81. The integrated optical apparatus of Claim 74, wherein said planar waveguide and said DBR are formed over a substrate and said DBR is disposed between said planar waveguide and said substrate such that light scattered outside said portion of said optical path and toward said substrate is reflected by said DBR toward said grating.

82. The integrated optical apparatus of Claim 81, wherein DBR is formed on a layer of material formed over said substrate.

83. The integrated optical apparatus of Claim 73, wherein (i) said plurality of elongate scattering elements have respective scatter-cross-sections adapted to scatter light along at least a portion of a predetermined optical path and (ii) a pair of Distributed Bragg Reflectors (DBRs) is positioned on opposite sides of said grating such that light scattered outside said portion of said optical path is reflected by said DBRs towards said grating.

84. The integrated optical apparatus of Claim 83, wherein said pair of DBRs are spaced apart from each other a distance to provide an optical cavity resonance for said scattered light.

85. The integrated optical apparatus of Claim 83, wherein said planar waveguide and said pair of DBRs are formed over a substrate, one of said DBRs being disposed between said planar waveguide and said substrate such that light scattered outside said portion of said optical path and toward said substrate is reflected by said one of said DBRs towards said grating.

86. The integrated optical apparatus of Claim 73, wherein (i) said plurality of elongate scattering elements have respective scatter cross-sections adapted to scatter light along at least a portion of a predetermined optical path and (ii) a gas-filled cavity is positioned with respect to said grating such that light scattered outside said portion of said optical path is reflected by said cavity toward said grating.

87. The integrated optical apparatus of Claim 86, wherein said planar waveguide is formed over a substrate and at least a portion of said gas-filled cavity is in said substrate.

88. The integrated optical apparatus of Claim 87, wherein said substrate comprises a silicon wafer.

89. The integrated optical apparatus of Claim 88, wherein said substrate further comprises a silicon dioxide layer formed on said silicon wafer.

90. The integrated optical apparatus of Claim 88, wherein said substrate further comprises one or more layers of material formed on said silicon wafer.

91. The integrated optical apparatus of Claim 86, wherein said gas-filled cavity is filled with air.

92. The integrated optical apparatus of Claim 86, wherein said planar waveguide comprises cladding and said gas-filled cavity is in at least a portion of said cladding.

93. The integrated optical apparatus of Claim 73, further comprising:

a cladding over said plurality of elongate scattering elements; and

an anti-reflection coating over said cladding for reducing reflections.

94. The integrated optical apparatus of Claim 93, wherein said anti-reflection coating comprises a multilayer stack.

95. The integrated optical apparatus of Claim 94, wherein said anti-reflection coating comprises alternating layers of semiconductor and dielectric material.

96. The integrated optical apparatus of Claim 95, wherein said anti-reflection coating comprises alternating layers of silicon and dielectric material.

97. The integrated optical apparatus of Claim 94, wherein said anti-reflection coating comprises multiple layers of dielectric material.

98. The integrated optical apparatus of Claim 97, wherein said dielectric material is selected from the group consisting of silicon dioxide and silicon nitride.

99. The integrated optical apparatus of Claim 93, further comprising an optical element oriented with respect to said grating coupler so as to provide an optical path directed at said predetermined angle with respect to said grating coupler, said grating coupler coupling light between said planar waveguide and said optical element.